Furrow Irrigation Infiltration with Multiple Traffic and Increased Axle Mass

R. R. Allen, J. T. Musick

Abstract. *Pullman clay loam and related soils in the Southern High Plains are slowly to moderately permeable, and furrow wheel traffic reduces irrigation infiltration rates. Traffic effects were evaluated with treatments of one (1) and two (2) furrow passes with relatively light (L) and heavy (H) tractors of 4.1 and 8.2 Mg (9,000 and 18,000 lb) mass, respectively, having 75% of the mass on the rear axle. Treatments are designated L-1, L-2, H-1, and H-2. Both larger tractor mass and repeated traffic increased tillage zone compaction and reduced irrigation infiltration rates and total infiltration. Soil strength (cone penetrometer) from wheel traffic compaction was greatest at the 100 to 150 mm (4 to 6 in.) depth for all treatments, which is near the bottom of the 150 m (6 in.) primary tillage zone. For the first 8-h infiltration test after tillage, using a flowing furrow infiltrometer, the L-1, L-2, H-1, and H-2 treatments reduced average infiltration by 23, 33, 38, and 43%, respectively; compared with 212 mm (8.3 in.) of infiltration for the no-traffic check. Because of furrow surface layer consolidation after the first irrigation, infiltration for all treatments was about 20% less during the second tests about 60 days later. The check infiltrated 171 mm (7.3 in.) and traffic induced infiltration reductions were 16, 23, 28, and 36%, respectively, for L-1, L-2, H-1, and H-2 treatments. A better understanding of variable furrow traffic effects on irrigation infiltration enables producers to improve water application efficiency by using traffic compaction to reduce excessive early season infiltration or by limiting traffic where low infiltration is a concern later in a crop season.*
Keywords. *Irrigation, Furrow irrigation, Compaction, Infiltration.*

On the Central and Southern High Plains, about 50% of the irrigated area uses graded furrow irrigation. Furrow irrigation is the predominate method on slowly-permeable clay soils. Preplant irrigations of 150 to 250 mm (6 to 10 in.) have been measured after winter tillage on the fine-textured Pullman clay loam in the Amarillo, Texas, area (Musick and Lamm, 1990) which is in the 2.5 mm/h (0.1 in./h) basic infiltration rate class. These relatively high irrigation amounts can occur even though the rooting zone soil water storage deficit may be less than 100 mm (4 in.) (Allen and Schneider, 1992). Excess infiltration results in losses of water and nutrients to soil profile drainage and reduced application efficiency.

The beneficial effects of planned traffic in all furrows, as a furrow irrigation management tool, have been reported for moderately permeable to slowly permeable clay loams in the Southern High Plains by Allen and Musick (1992); Allen and Schneider (1992); Musick and Pringle (1986); Musick et al. (1985); and Musick and Walker (1987). The reported furrow water infiltration reductions from traffic ranged from 20 to 35% with advance times being reduced by about one half.

Kemper et al. (1982) reported that wheel traffic reduced infiltration rates on silt loam soils at 15 locations in the Twin Falls, Idaho, area by 12 to 80%. In these cases, the wide range in infiltration effects from traffic were largely attributed to varying soil water contents at the time of compaction. On a similar silt loam soil near Kimberly, Idaho, Trout and Kemper (1983) reported that advance time was 1/3 and steady state infiltration rate was 1/2 that of non-traffic furrows when a tractor wheel packed the soil ahead of the furrow opener. Eisenhauer et al. (1982) reported that wheel traffic reduced furrow infiltration up to 20 to 25% during the first application after tillage in South Central Nebraska when both conventional and reduced tillage systems were tested. Yoder et al. (1989) evaluated infiltration and wetting patterns beneath adjacent wheel and non-wheel furrows on a very fine-sandy loam in Western Colorado and reported more infiltration and slightly more lateral movement of irrigation water from non-compacted furrows.

Regardless of the width of the row crop equipment used, which mostly varies from 4 to 12 row units, at least two furrows are compacted by tractor wheels and an additional two furrows may be compacted to a lesser degree from implement gauge wheels. After furrowing; the operations of preplant bed-furrow cultivation, herbicide application, and planting can result in two or more tractor passes through traffic furrows before growing season irrigations are applied. Thus, there can be added compaction effects from multiple passes or from increased tractor mass or axle load with relatively heavy equipment.

Soane et al. (1981) working in the United Kingdom, reported that the second pass of a wheel usually produces

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less increase in compaction than the first pass. However, the response to multiple passes will depend on the initial soil density and strength distribution with depth. For loose soils, compaction effects are much greater during the first pass than subsequent passes. Whereas, on soils which have appreciable initial strength, the compaction effect from the first pass may differ very little from subsequent passes. They also reported that the zone of maximum compaction approaches the surface with repeated passes. However, Voorhees et al. (1978) did not find this to be true in a 5-yr study in the Northern Cornbelt, possibly because of winter freezing action which decreased compaction in the 0 to 150-mm (0 to 6-in.) depth. In another study, Voorhees (1979) measured bulk density to the 300-mm (12-in.) depth after multiple passes with a 7.3 Mg (16,000 lb) mass tractor. After one pass, increase in compaction was greatest in the 0 to 75-mm (0 to 3-in.) depth, but after three passes the compaction increased with depth and was greatest from the 150 to 300-mm (6 to 12-in.) depth.

The objectives of this experiment were to determine the effects of tractor mass and repeated furrow traffic on: (1) degree and depth of compaction; and (2) irrigation infiltration.

Procedure

The study was conducted in 1991 and 1993 at Bushland, Texas, on relatively short 100-m (325-ft) length furrows, spaced 1.0 m (40 in.) apart with no slope so that water infiltration would be relatively uniform along the furrow length. Plots were 10 m (33 ft) wide and were arranged in a randomized block design with four replications. The soil, a fine textured and slowly permeable Pullman clay loam (Torrertic Paleustoll), was described by Unger and Pringle (1981). This soil has a Ap horizon to about the 150-mm (6-in.) depth, which is also the depth penetrated by most tillage operations. A relatively dense clay Bt horizon extends from 150 to 750 mm (6 to 30 in.) in depth, having bulk densities of 1.5 to 1.6 Mg/m^3 (100 lb/ft^3). The clay fraction is dominated by montmorillonite, and the soil profile, when dry, develops shrinkage cracks that result in a relatively high initial water infiltration rate. After filling of cracks or saturation of a loosened surface layer, infiltration rates decline to a low rate after 2 to 3 h and reach a basic rate after 8 to 12 h. The soil holds about 180 mm (7.2 in.) of plant available soil water at field capacity (FC) to the 1.2-m (4-ft) depth.

Soil preparation was accomplished by disking and chiseling 0.15 m (6 in.) deep to incorporate residue from the previous crop. In each plot, 8 bed-furrows were formed with two passes of a 4-row lister. On traffic treatments, tractors were driven on all furrows. Two tractors were used: a Deere 3020 with 4.1 Mg (9,000 lb) mass and a Case 2290 with a rear mounted tool carrier totaling 8.2 Mg (18,000 lb) mass. These tractors are designated light (L) and heavy (H), respectively, and span the mass range of many row crop tractors for 4 to 12-row equipment. The tractors were ballasted so that about 75% of the total mass was on the rear axle, which is common practice for two-wheel-drive tractors (Woerman and Bashford, 1983). Rear tire sizes were 15.5 × 38 R1 bias and 18.4 × 38 R1 bias, respectively, for the L and H weighted tractors. Rear tire inflation pressures were 83 kPa (12 psi) and 166 kPa (24 psi), respectively, for the L and H tractors. Furrow treatments are listed as follows:

Ck = No furrow traffic
L-1 = Light tractor, 1 pass
L-2 = Light tractor, 2 passes
H-1 = Heavy tractor, 1 pass
H-2 = Heavy tractor, 2 passes

After furrow traffic treatments were applied, gravimetric soil water contents were obtained by 0.3-m (12-in.) core increments to the 1.8-m (6-ft) depth. Soil cone index measurements were made in furrows with a tractor-mounted, hydraulic-powered, cone penetrometer to the 0.6-m (24-in.) depth for an indication of soil strength after trafficking. The cone penetrometer, designed and constructed by G. L. Barker (USDA-ARS Lubbock, Texas), is similar to a unit described by Williford et al. (1972). The penetrometer tip diameter was 20.27 mm (0.798 in.), and the shape and rate of tip travel conformed to ASAE Standard 5313.2 for soil cone penetrometers (ASAE, 1989). Soil bulk density measurements were made in 50-mm (2-in.) increments to the 300-mm (12-in.) depth with a Troxler 3400 series nuclear density gage.

Infiltration measurements were made in 4.6-m (15-ft) blocked furrow sections with a flowing furrow infiltrometer, similar to that reported by Dedrick et al. (1985). The measurements were made immediately before the first irrigation (preplant) in May of each year and just before the second irrigation when grain sorghum was at about the boot stage of growth in July or early August. Treatment means were tested for significance at the $P<0.05$ level using Statgraphics (Manugistics, 1992) for analysis of variance. Grain sorghum was grown to deplete soil water content after the preplant irrigation and ensuing June rainfall occurring before the second infiltrometer measurement. Evaluation of soil compaction effects on grain yield were not included in the scope of this study.

Results and Discussion

Bulk Density and Soil Strength

Soil bulk density values are presented in table 1. The bulk density values were obtained at the 100 to 150-mm (4 to 6-in.) depth, corresponding to the depth of peak soil strength (penetrometer cone index) as presented in figure 1.

Voorhees et al. (1978) reported penetrometer resistance to be more sensitive to differences in compaction than bulk density. They found that wheel traffic increased bulk density up to 20%, and differences were not significant below the 150-mm (6-in.) depth. In contrast, the

Table 1. Soil bulk density values at the 100 to 150 mm (4 to 6 in.) depth near the bottom of the Ap soil horizon immediately after furrow traffic compaction

Treat-ment	3-25-91 Bulk Density Mg/m^3	3-25-91 Bulk Density (lb/ft^3)	3-25-91 Increase (%)	4-2-93 Bulk Density Mg/m^3	4-2-93 Bulk Density (lb/ft^3)	4-2-93 Increase (%)
Check	1.15	(71.8)	0	1.12	(69.9)	0
L-1	1.20	(74.9)	4.3	1.21	(75.5)	8.0
L-2	1.27	(79.2)	10.4	1.33	(83.0)	18.8
H-1	1.32	(82.4)	14.8	1.39	(86.7)	24.1
H-2	1.36	(84.9)	18.3	1.40	(87.4)	25.0
LSD (005)	(0.11)	(6.8)		(0.12)	(7.5)	

n = 8.

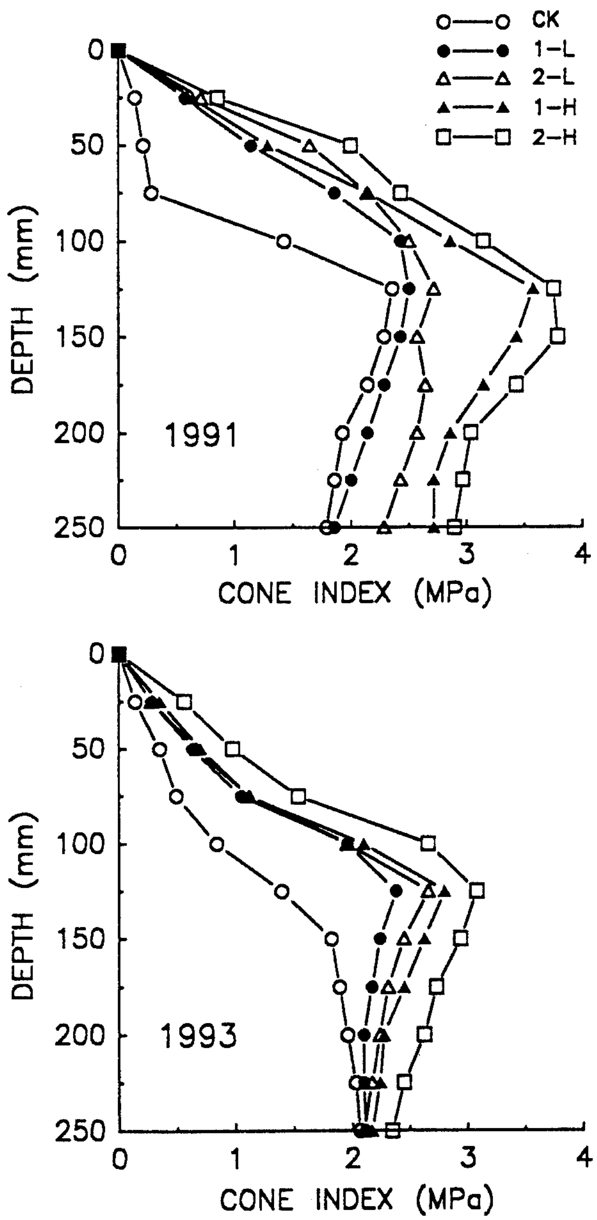

Figure 1–Cone index values of soil strength with depth obtained immediately after furrow traffic compaction (25 mm = 1 in., 1 Mpa = 145 psi).

corresponding increases in cone resistance caused by traffic were up to 400%. In this study, bulk densities were similarly increased from 18 to 25% by the most severe (H-2) traffic treatment (table 1). Bulk density values under traffic furrows were higher in 1993 than in 1991 because of higher soil water content and increased compaction during trafficking. Bulk densities for the H-1 treatments were 10 to 15% higher than for the L-1 treatments, and the second pass of the heavy tractor increased density only slightly. Unger and Pringle (1981) report bulk densities for undisturbed Pullman clay loam beneath the normal tillage zone in the Bt horizon from 150 to 400 mm (6 to 16 in.) in depth to average 1.48 Mg/m^3 (92.5 lb/ft^3). In this soil, most compaction from traffic (bulk density increase) occurs within the tillage depth zone, and bulk densities of the naturally dense Bt horizon are affected very little.

In both years of this study, soil strength (fig. 1) under traffic furrows peaked at the 100 to 150-mm (4 to 6-in.) depth which is the bottom of the Ap top soil horizon. The cone index values were less in 1993 because of higher soil water content (65% FC) at the time of measurement compared with drier soil (30 to 40% FC) at the time of trafficking in 1991. This emphasizes that soil strength measured by penetrometer is a function of soil water content, as well as, soil bulk density which must be considered when making comparisons of different dates. In 1991, cone index values for the check increased markedly at the 75 to 125-mm (3 to 5-in.) depth when primary tillage had been rather shallow. In contrast, primary tillage in 1993 was 150 mm (6 in.) in depth which is reflected by lower cone index values in the tillage zone. In both years, two passes of the light tractor did not produce as much compaction (bulk density or soil strength) as did one pass with the heavy tractor.

INFILTRATION

Cumulative infiltration depth curves obtained from infiltrometer data are presented in figures 2 and 3. Total cumulative infiltration amounts for all treatments are presented in table 2 for individual years, including 2-yr

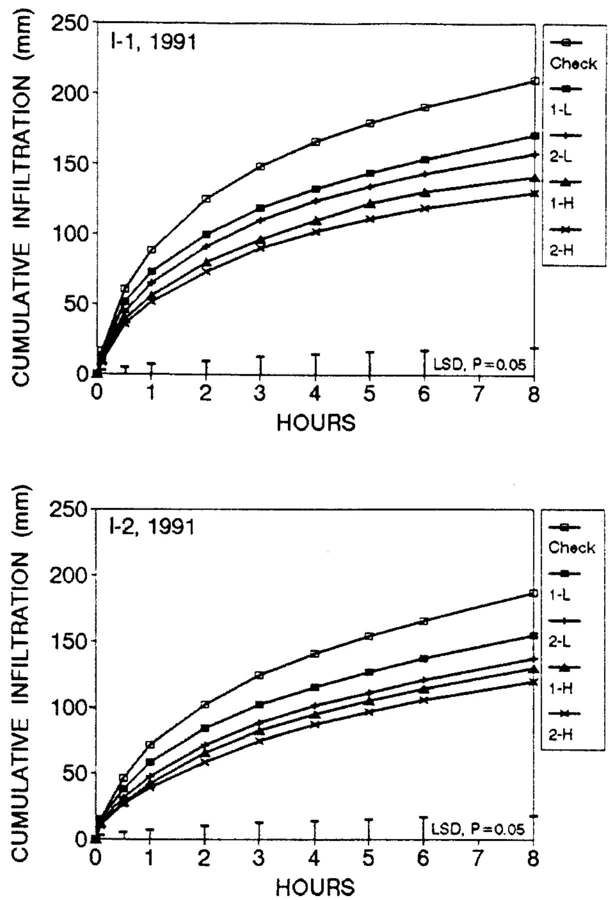

Figure 2–Cumulative irrigation water infiltration with time for the first (I-1) and second (I-2) applications in 1991 (LSD = least significant difference) (25 mm = 1 in.).

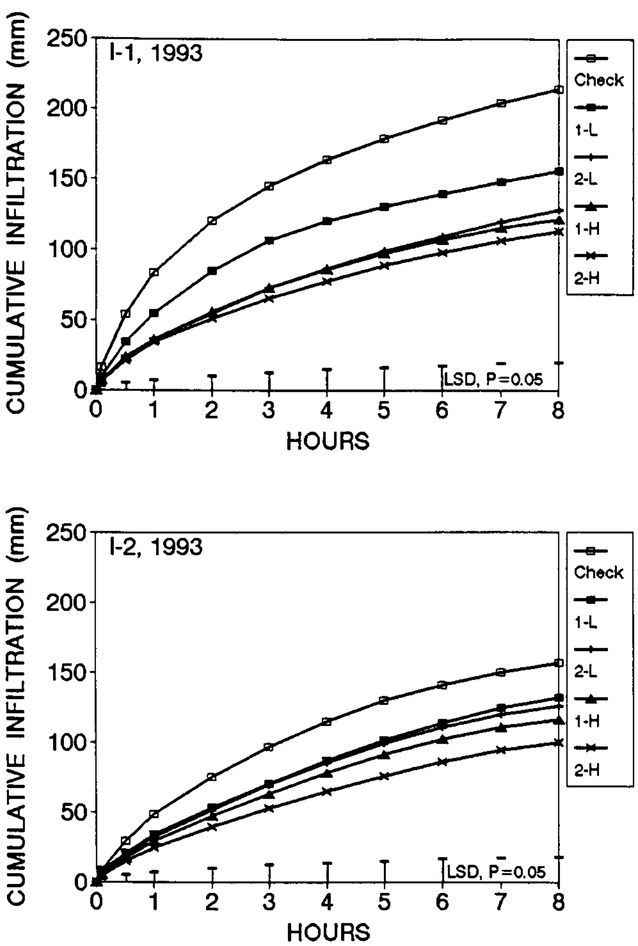

Figure 3–Cumulative irrigation water infiltration with time for the first (I-1) and second (I-2) applications in 1993 (LSD = least significant difference) (25 mm = 1 in.).

averages. The average effects of higher mass tractor load and repeated traffic on cumulative infiltration during tests are evident in table 2. Average infiltration reductions from traffic ranged from 23% for the L-1 treatment to 43% for two passes with the high mass (H-2) tractor during the first (I-1) test after primary tillage. In comparison, infiltration reduction effects from traffic were less for the I-2 tests after furrow consolidation, ranging from 16% for 1-L to 36% for 2-H treatments.

One pass of both L and H mass tractors significantly reduced infiltration, however the further infiltration reduction from a second tractor pass was not statistically significant, except in test I-1 in 1993. Although the infiltration reduction effect from a second tractor pass may not be statistically significant, there still is an effect.

Total infiltration amounts for the check treatments were nearly equal for the I-1 tests in both years, however, infiltration reductions from traffic were larger in 1993 because of wetter soil (65% FC) during trafficking and a greater compaction effect on infiltration, which is apparent in figures 2 and 3 and in table 2. Even the light tractor caused considerable compaction on wet soil and a resulting 27% and 39% reduction in infiltration for one and two passes, respectively. Infiltration amounts for all treatments during the I-2 tests in 1993 (fig. 3) are lower than in 1991 (fig. 2), because of moist soil (50 to 60% FC) caused by

Table 2. Total cumulative irrigation infiltration amounts during 8-h infiltrometer tests and percent infiltration reduction as affected by wheel traffic compaction treatments, Pullman clay loam, Bushland, Texas

	1991			1993			Average		
	Total Infilt.		Reduction	Total Infilt.		Reduction	Total Infilt.		Reduction
Treat.	mm	(in.)	(%)	mm	(in.)	(%)	mm	(in.)	%
Test I-1									
Check	210	(8.3)	0	215	(8.5)	0	212	(8.3)	0
L-1	170	(6.7)	20	156	(6.1)	27	163	(6.4)	23
L-2	158	(6.2)	25	128	(5.0)	39	143	(5.6)	33
H-1	141	(5.5)	33	122	(4.8)	43	131	(5.2)	38
H-2	129	(5.1)	40	113	(4.4)	47	121	(4.8)	43
LSD (0.05)	(0.22)	(0.8)		(0.25)	(1.0)				
Test I-2									
Check	187	(7.4)	0	156	(6.1)	0	171	(6.7)	0
L-1	155	(6.1)	17	132	(5.2)	15	143	(5.6)	16
L-2	138	(5.4)	26	126	(5.0)	19	132	(5.2)	23
H-1	130	(5.1)	30	116	(4.6)	25	123	(4.8)	28
H-2	120	(4.7)	36	100	(3.9)	36	110	(4.3)	36
LSD (0.05)	(0.21)	(0.8)		(0.20)	(0.8)				

100 mm (3.9 in.) of rainfall (65% above average) during a 30-day period before I-2 tests were conducted.

Irrigation Management Implications

These results provide furrow irrigators information concerning traffic compaction effects on irrigation water infiltration which can be helpful for management decisions.

There can be both positive and negative effects from furrow traffic compaction as discussed in the introduction. In instances where infiltration rates are excessively high during the first irrigation after tillage, planned traffic in all furrows can be beneficially used to reduce the high infiltration. Or, irrigators may elect to lightly compact (low mass equipment) all furrows in order to have water advance more uniformly and simplify management. However, in either case, this early season traffic compaction of all furrows on moderately to slowly permeable soils may require more frequent irrigations because of lower infiltration on each application later in the crop season.

A negative aspect of furrow traffic compaction is the difference in infiltration between wheel track and non-track furrows, especially with relatively high mass tractors in common use that can cause infiltration reductions in the 40 to 50% range. Irrigation advance rates in these traffic furrows can reach about two times that in nontraffic furrows (Allen and Musick, 1992), thus requiring extra management care to avoid excessive runoff. In order to minimize the need for furrow flow adjustments caused by differential advance and infiltration between traffic and non-traffic furrows, traffic can be confined to as few furrows as possible such as two furrows per tractor pass using relatively wide 8 to 12-row equipment, thereby reducing the compacted area in comparison with narrower 6-row equipment. Where repeat traffic is necessary, it can be confined to the same traffic furrows because the second pass has less infiltration effect than does a single pass in a non-trafficked furrow.

Wet soil further increases compaction even by light tractors, but time-of-opportunity windows may not permit waiting for soil drying. Fortunately on this soil and other similar fine-textured soils, most traffic compaction occurs within the 0 to 150-mm (0 to 6-in.) depth which can be corrected later by primary tillage.

Conclusions

1. In this fine-textured soil, most compaction occurs within the tillage zone (Ap horizon), and soil strength and bulk density of the naturally dense Bt subsoil are affected very little. Soil strengths (cone penetrometer) from wheel traffic compaction peaked at the 100 to 150 mm (4 to 6 in.) depth which is the bottom of the Ap soil horizon.
2. Soil strength measured by cone penetrometer was more sensitive to variation in compaction than was bulk density.
3. Increased tractor mass further reduced irrigation water infiltration. The greatest infiltration reduction effect from compaction occurred during the first traffic pass for both light and heavy tractors.
4. Traffic induced reductions in infiltration were about 20% less during the second infiltration tests because of furrow surface consolidation from the first irrigation.
5. Relatively moist soil (above 60% FC) during traffic especially increased compaction and decreased irrigation infiltration even for a relatively light 4.1 Mg (9,000 lb) tractor.

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